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ABSTRACT

An overview of computer animation and the techniques involved in its creation is provided in the introduction to this masters thesis, which focuses on the problems encountered by students in learning the forms and functions of complex anatomical structures and ways in which computer animation can address these problems. The objectives for, problems with, and solutions to the creation of data and animation for a three-dimensional computer model of the skeletal system are discussed, as well as their implications for medical animation and prosthetics. Applications in the field of education and in interactive videodisc systems are also considered. Discussions of future possibilities for medical animation and applications of such model systems in research, sports, the arts, and entertainment conclude the thesis. A glossary of medical terms used and a list of 13 references are provided. (MES)

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COMPUTER GRAPHICS RESEARCH GROUP

ED285517

THE REPRESENTATION OF ANATOMICAL STRUCTURES THROUGH COMPUTER ANIMATION FOR SCIENTIFIC, EDUCATIONAL AND ARTISTIC APPLICATIONS

A Thesis

Presented in Partial Fulfillment of the Requirements for the Degree of Master of Arts

by

Donald Larry Stredney, B.S.

The Ohio State University
1982

Approved by

Charles A. Csuri
Advisor
Department of Art Education

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THESIS ABSTRACT

THE OHIO STATE UNIVERSITY
GRADUATE SCHOOL

NAME: Donald L. Stredney QUARTER/YEAR: Spring/1982

DEPARTMENT: Art Education DEGREE: Master of Arts

TITLE: The Representation of Anatomical Structures through Computer Animation for Scientific, Educational, and Artistic Applications

This study presents an overview of computer animation and the techniques involved in its creation. Problems with cognition when dealing with complex anatomical structures are outlined and discussed. The objectives, problems and solutions to the creation of data and animation for a computer model of the skeletal system are given. Implications in medical animation and prosthetics are discussed, as well as applications in the field of education and interactive videodisc systems. Future possibilities for medical animation and applications of such model systems in research, sports, the arts, and entertainment are explored.

Charles A. Csuri
Advisor's Signature

This Thesis is Dedicated to Chicken George

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Chapter 1: Introduction

Computer animation is a process of constructing, calculating, and filming animation through the use of a computer. The environment is usually made up of a computer; peripherals such as disk drives, frame buffers, and tape drives; and display monitors on which to view the frames of animation. A digital computer is used for high speed calculations that are involved in the manipulation of data. This data is numerically represented in the computer's memory. Peripheral memory is available on the disks. This memory allows the user to randomly access information at will in addition to storing data for future reference. The basic function of a frame buffer is to store a frame or several frames of animation in its own memory and allow the user to playback one or several frames of animation in succession.

All objects or pictures must be entered into the computer or into the peripheral memory in numerical fashion. This process is called "digitizing" the picture or object. The animator must generate or create the mathematical representation of that object in the computer. The files that represent the object or picture data in the memory are simply a list of points in three dimensions followed by a

list of numbers representing the individual polygons or faces of an object. This tells the computer how many points there are to delineate the object and in what order to connect the points to describe its surface form.

The supporting software for the machines or hardware consists of the programs to create, manipulate, and display the objects on a display device. In the animation, this display device is generally a cathode ray tube (CRT).

Software used for the generation of data are those that permit a user to create either a finished structure or a basic structure. Additional programs have been comprised to alter either the position or the form or size of the object. These exist by themselves or as subroutines of display algorithms.

There are display routines for calligraphic or line displays. These allow the user to view the linear representation of the object, much similar to a wire-frame structure. Other routines allow for the display of the object or scene by calculating the surface form of the data and representing it in the frame buffer complete with color, reflectance, transparency and size. These are termed raster displays. They allow one to see the object as it would exist in reality.

By changing the position, size, or any of the other attributes of the object or the scene at distinct intervals, one can create an animated sequence. The playback of these changes allows the user to view the objects in motion or to see them in all their manifold expressions. These calculated frames can then be stored on the disk. These stored frames can be reloaded back into the frame buffer in succession and either filmed or recorded on videotape. The hard copy representation of the data i.e. the film or videotape is the final product of computer animation.

An artist tries to maintain a sense of intuition when using the computer. Serendipity need not rule, but one tries to establish a sense of freedom when working in this medium. The artist is confronted at first by a sense of distance. There is a lack of direct sensory contact with the medium. If this can be overcome, and if one can concentrate on the possibilities of the system, the creative process can prevail. In time, a sense of control and confidence emerges.

The great advantage is the ability to manipulate a structure, a group of structures or a scene, at will with a relatively short interval of time to view the results. Hence the computer becomes an experimental tool in which the

artist can create or depict a scene, and change any quality of the objects or scene.

It has been helpful to understand the process a programmer must go through to write a complex program. This understanding is prerequisite to successful communication with programmers in a technical language. Animation often requires special programming. An animator needs to communicate with programmers concerning these special requirements. The improved design of subroutines allow the artist to interact with the computer in a more direct and user friendly fashion. Such subroutines can free the artist to be more creative and to work in a more natural manner.

The focus of this thesis shall be on the creation of complex three dimensional anatomical data. The various problems of learning the form and function of anatomical structures will be discussed, as well as how animation, and specifically computer animation can address these problems.

Chapter 2: Current Practice: Advantages and Disadvantages

We live in a three-dimensional world. Yet traditionally we have taught spatial-tactile subject matter through textbooks and lectures.

In medicine, specifically in the sphere of anatomy, the need to acquire a spatial understanding becomes prerequisite. As a teaching assistant in gross anatomy, the author found that learning is directly contingent upon the students' comprehension of the shapes of organs and systems as they exist in three-space. Without such an understanding, even cardinal terms such as superior and inferior, or medial and lateral, when introduced to a new organ or system become a major stumbling block for assimilation. This is especially true when studying with a subject which is highly irregular and complex in configuration e.g., the nervous system. Techniques such as coronal, transverse, or saggital sectioning seem to confound rather than clarify. (Figure 1.)

Learning becomes more difficult when one enters the more abstract studies of histology and physiology. Here, the prepared slide of tissue, sectioned by the microtome, proffers only a two-dimensional glimpse of the structure in

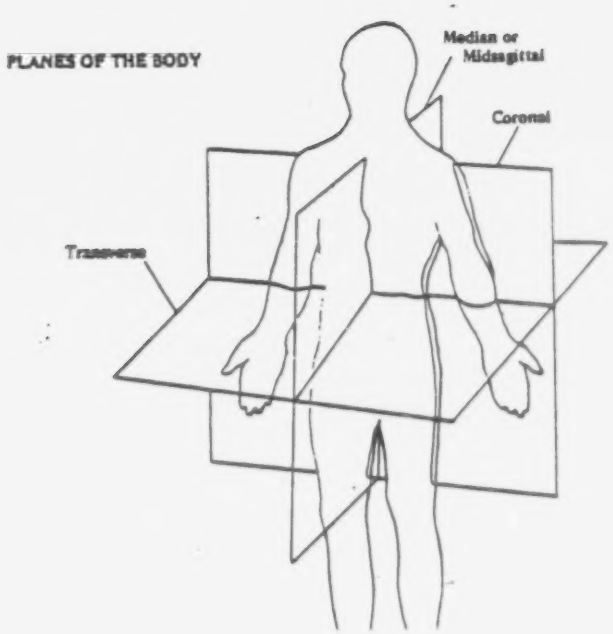

Figure 1. The Planes of the Body.

question. However, the student is expected to contort his mental image and conceptualize the entire shape from a fragment or sequence of fragments. Without a competent grasp of spatial cues, the student's understanding of function and form is greatly impaired. This cerebral flip-flop and mental manipulation of the structure back into three-space often proves to confuse the student.

In the field of physiology the students' inability to construct temporal relationships becomes the paramount

learning obstacle. The interrelationships of complex structures and their occurrence over time quickly overwhelm the student.

Reductionism and sectioning are essential to scientific analysis. Yet in spite of this, detachment from the entire view can at times confuse and disorient even the brightest of students. If however, structures are displayed three-dimensionally first whole and not sectioned, and then sectioned, with the process occurring in full view, understanding can be promoted. If the student can manipulate the section in three-space, and in real-time, many mental blocks which inhibit learning can be removed. Clear, spatial-temporal demonstrations can eliminate these misunderstandings.

Human anatomy is taught by using the traditional methods of gross dissection. Those universities that are fortunate have prosected cadavers as their main teaching aids. These are augmented by 35mm slide illustrations of gross dissections, disarticulated bones, gross sections enclosed in plastic cases, and clinical x-rays. Graduate level and medical courses start with fresh remains in addition to all of the aids mentioned above.

One problem is found with these methods is the fixation of the bodies. The reference position used in instructional material is the "anatomical position". This position consists of the body standing erect, face forward, feet together, arms at the sides, and palms facing the observer. Unfortunately, the body in the preserved state rarely assumes this position. Instead, it assumes a more natural relaxed position. The legs are usually rotated laterally and the palms medially. This can cause students to lose reference, especially when dealing with the extremities.

While gross dissection is a "tried and true" method of teaching anatomy, it may not necessarily be the best or the most advantageous. Extreme patience and dexterity with dissecting instruments are required in order to accurately perform a proper dissection. In addition, often several structures must be sacrificed or destroyed in order to sustain the integrity of a particular structure. Dissection of a system as complex as the human body can be an exasperating experience for a novice in anatomy.

Peripheral aids in anatomy are useful, yet they can also be confounding. If a student is not properly oriented to a slide, all structures depicted can be meaningless. A proper understanding of a slide and its orientation in

relation to the entire body is the only way to glean its information. Specific structures to be studied need to be enhanced or highlighted, in some way, in order to promote learning. True medical illustration can help clarify and enhance particular structures. Yet the etiology of a certain section or view would be most beneficial to the students' understanding. Illustrations lack temporal and interactive qualities. Animation however, exploits perspective, color, and temporal cues. Structures can be more advantageously shown, as well as the process of obtaining a given view or structure.

Sections enclosed in plastic have similar disadvantages as teaching aids. The students' questions are, "Where exactly does this section come from? How is it oriented? and, How did they produce the section?".

Similar questions emerge when one looks at a disarticulated bone. Two things must be known to properly orient oneself to the structure: 1) Is it a structure that is always located either medially or laterally? and 2) Is it a structure that is either superior or inferior or one that is either anterior or posterior? Without these key elements of direction, the entire object and its markings are meaningless.

The reading of x-rays presents a similar problem . What structure is in front of or behind what structure? Without the assistance of one well versed in the structures and in reading x-rays, the student is helpless. It would be a great advantage for a student learning about a particular bone for the first time, to be able to view that bone as it exists in the overall skeletal system as well as from a more conspicuous viewpoint for detailed reference. What is stressed here is the value of relationships. Understanding how each structure relates to the entire system configuration is essential to understanding both form and function in anatomy.

Chapter 3: Animation: a Solution to Disorientation in the Study of Anatomy

During the summer of 1978, I served as an intern illustrator/animator at the National Medical Audiovisual Center/ Center for Disease Control in Atlanta, Georgia. One soon learns of the tremendous effort required to create a great piece of animation. My project director commented on this effort, "There is nothing more exciting to see than good animation," he said, "and nothing more tedious and boring to create."

The difficulty with traditional animation is the tedious effort that an artist or illustrator must undergo to create any given length of film footage. In addition, the drawings, once they are executed, serve to depict only that which they were designed to depict. Only that particular structure, in that particular color, in that size, and that orientation is available to the viewer.

Here, computer animation offers a distinct advantage. After the initial effort and cost of digitizing the structure and storing it in the computer's memory, that data can be manipulated in a myriad number of ways. The computer model can be viewed from any orientation. Any of its various

attributes, such as color, reflectivity, transparency, size, and even shape can be altered to achieve any given number of efficacious goals. The model can be copied into a manifold number of similar or different copies. The turn-around time is much shorter with computer animation. By using the advantages of quick turnaround and real-time playback, the animator can work much more closely with the focus of the animation. A more accurate depiction with a greater sense of realism can be achieved in a fraction of the time of traditional methods. Once it is entered into memory, it can be called upon even years later to serve a new purpose in an entirely different situation.

Computer animation permits the viewer to transcend the limits of reality. The computer can depict the dissolution of layers of tissue to reveal hidden structures. The viewer can travel through areas that are are impossible for him or her due to size, but not imagination. It allows one to enter the microscopic world and view occurrences that happen too rapidly for the eye to see; and it allows us to scale the macroscopic world to the point where we can view it in its entirety, with things that occur over years taking place in minutes.

Quite simply, computer animation allows one to depict

those situations that cannot be shown in any other way or even situations that exist only within the mind itself. The computer allows the animator to experiment with various combinations and views of animation. This allows for a more creative environment, and increases the possibility of the pleasant surprise of serendipity.

Chapter 4: Skeletal Animation

Section 1. Skeletal Movement Programs

Initially at the Computer Graphics Research Group, I worked on a system comprised of a Vector General calligraphic display, a 10 bit frame buffer and a PDP 11/45 minicomputer. The great advantage of the system was that it employed a spatial data management system using a run length system. This allowed the user to store up to 120 or so frames on disk and retrieve them in real time. This was very useful. It permitted the artist to create a pencil test of a few seconds in length and allowed them to be viewed directly in minutes after calculation.

The difficulty in representing the human form is inherent in the complexity of the form itself. [5,3] But even the greatest complexity can be reduced and classified. First a simple model is to be created, and with that data the movement is studied, defined, and enhanced. In a similar fashion a simplified skeleton can be reduced from any living creature in order to study basic and complex movements. Work began on a simplified stick figure that walked. [7,8,9,11]. The problem was approached in the traditional animation style. A figure was created that went through the motions of

walking in one fixed place, as if suspended in space. The translation of the figure through space was brought about by animation commands to translate the objects, (i.e., arms, legs, spine, etc.) by commands in the animation language called ANIMA-II[6].

The initial figure representation was crude. Scaled cubes were used to simulate legs, thighs, and arms and a simple projection of a profile outline was used to depict a skull. However, the motion was rather convincing and this was the primary concern. The pelvis, a horizontal stick, would rotate correctly about the three cardinal axis (X,Y,Z). Although there were no hands or feet, both the upper and lower limb movement were quite convincing. (Figure 2.)

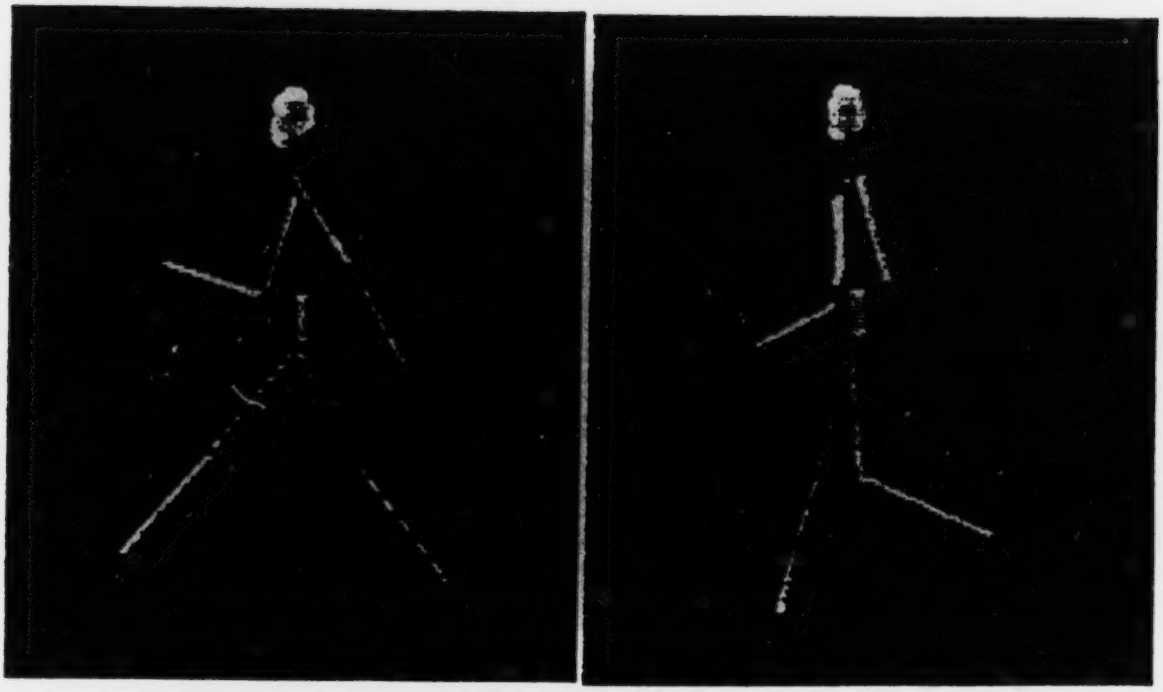

Figure 2. Frames from videotape of animation from the 11/45.

The Digital 11/45 minicomputer system was sold shortly after I reached this stage of my work. The ability to run pencil tests was no longer available on the new system. An animator who has worked for any degree of time in traditional mediums or computer graphics can understand the advantages of pencil tests. The chance to see a "quick and dirty" view of the movement, to check for accuracy and timing is critical to good animation.

The work continued on a Vax 11/780 system, using the ANTTS language (ANimated Things through Space and Time)[4]. It provided the opportunity to increase the realism of the figure. However the problem arose of controlling the linkage of the various joints. Each segment had to be translated from its body position back to the spatial coordinate origin, rotated accordingly, and then translated back to its new body position. Since there are over 200 joint articulations in the body this became a monumental task. Animation scripts had to be written to keep an accurate account of all these transformations. Something more simple was needed. Since the only way to achieve real-time playback was through film, due to the length of the scripts filming was never feasible.

In an attempt to resolve this problem I began working with a colleague, David Zeltzer, a computer science graduate student with a special interest in robotics and artificial intelligence. He was very interested, and in fact planning on implementing a skeletal animation system (SAS).

Initially work was on various robotic methods to move a multi-segmented arm with proper linkage during rather complex transformations. This work was executed on a Megatek calligraphic display system, which had the ability to store

several segments or frames in its own internal memory and then play them back in real time. Once again we had the critical ability to run pencil tests.

Work began on the design of a vector skeleton. It was comprised of simple vectors connecting joint to joint. The skeleton was proportionately correct, with a few liberties for simplicity. It was also anatomically precise. For instance there were twenty minute vectors for each phalanx and metacarpal in the hand. However the addition of such small vectors, although adding to the realism, served to slow down the playback speed and decreased the number of segments possible to store. Paddle-like hands were constructed that served the same movement function, yet allowed us to store almost twice as many segments in the internal buffer of the Megatek. (Note 1/4 of the bones of the body are found in the hands!) A similar convention was adopted for the feet. The head was designed from a simplified wire-frame profile of the skull in the mid-saggital plane and employed a movable jaw. Later more sophisticated data would replace the vectors in the final animation. (Figure 3,4.)

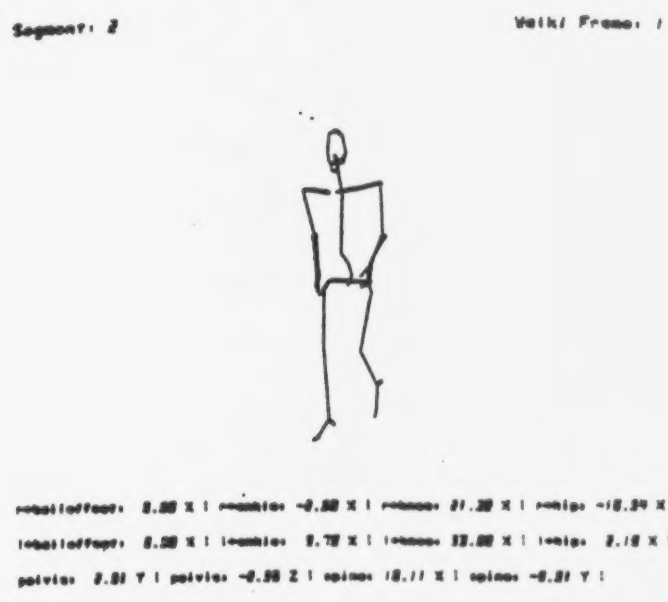

Figure 3. Frame off Megatek showing test parameters.

Scripts were written for the skeleton to move with a amazing degree of realism and freedom, including talking, bowing, gesturing, pirouetting. The skeleton could even do deep knee bends! The scripts were very straight forward and the skeletal animation system handled the problem of the joints disarticulating. (Figure 5.)

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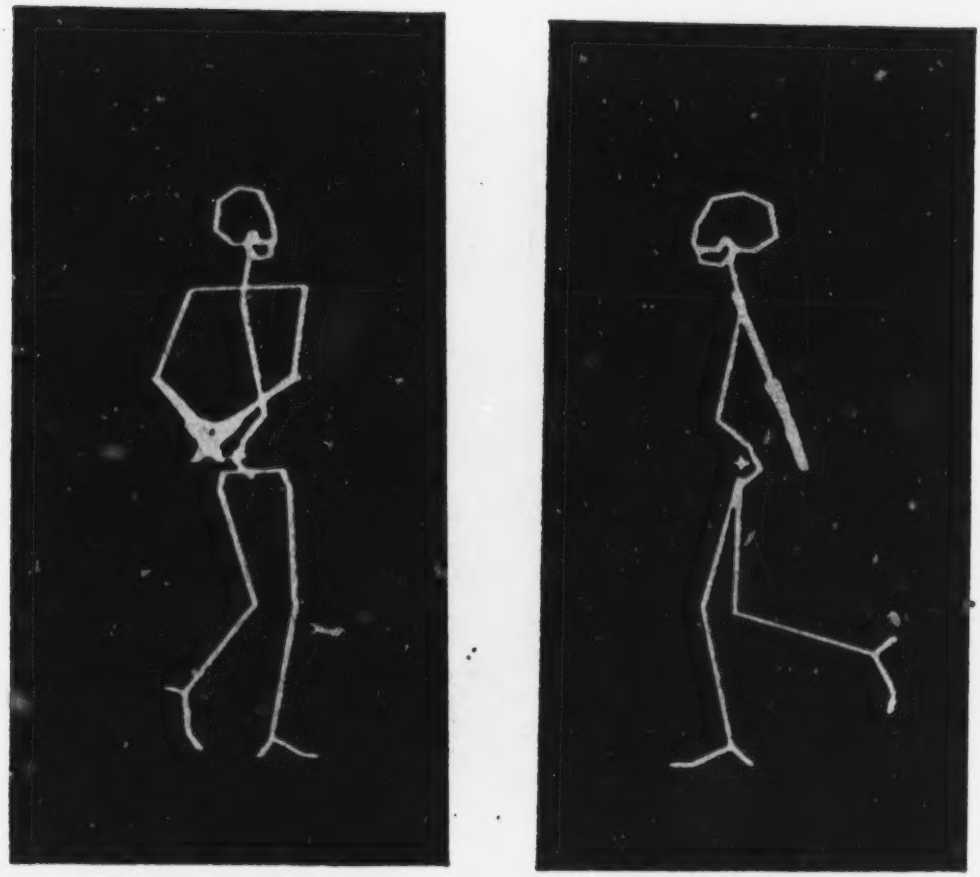


Figure 4. Frames from film for Canadian Man-Computer Communications Society '81.

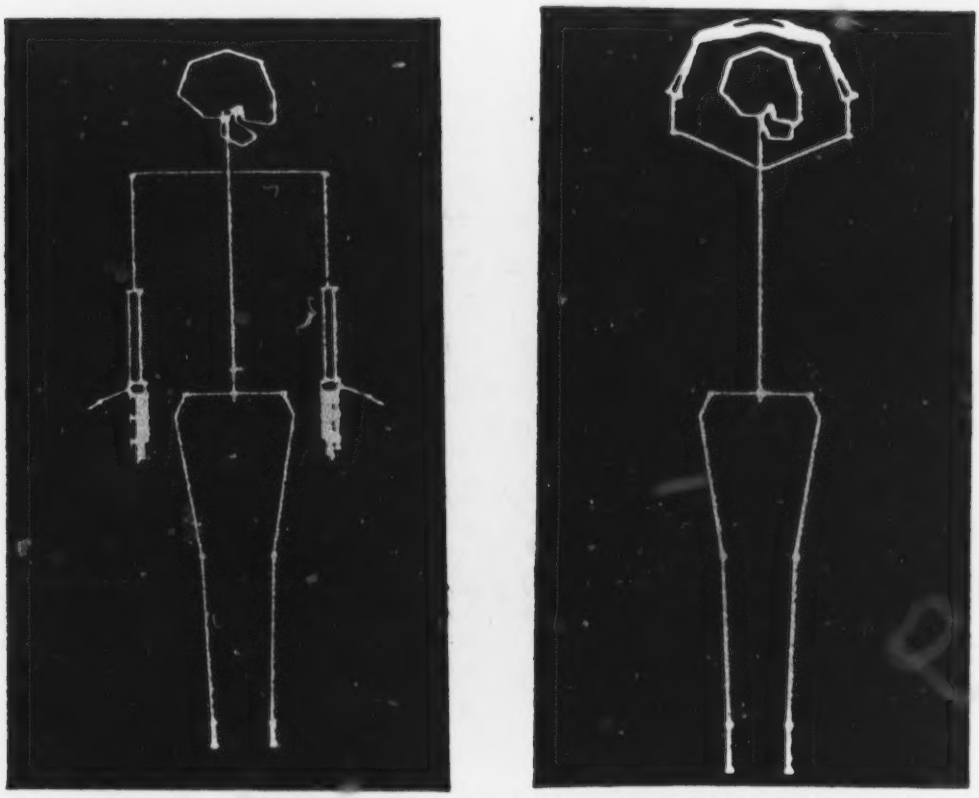


Figure 4. Frames from film for Canadian Man-Computer Communications Society '81.

However the need to write long scripts remained a problem. In order to make the skeleton move with any degree of realism and complexity over a period as brief as 2-3 seconds, it was necessary to write very lengthy animation scripts. True one could use traditional film conventions such as filming in reverse to make the skeleton return to an original position and double framing to stretch out the time over which the movement took place. But still the scripts were lengthy despite the use of such methods. The script

for the pirouette alone was close to 2000 lines of code!

The following is an example of this type of code. It sets the skeleton into a boxing position. (Note it is for only one frame)

```
/*********************************************************/
;;;;;;;;;; frame 1
v
e
0 0 2
bend
body
x
s
25
l_ankle
bend
r_hip
x
s
-55
s
bend
r_hip
z
s
-10
s
bend
l_hip
z
s
10
s
bend
r_knee
x
s
50
s
bend
r_ankle
x
```

```
s
-15
s
bend
r_shoulder
x
s
-25
s
bend
l_shoulder
x
s
-20
s
bend
r_elbow
x
s
-145
s
bend
l_elbow
x
s
-135
s
bend
r_wrist
x
s
-90
s
bend
l_wrist
x
s
-90
s
bend
r_palm
x
s
-90
s
bend
l_palm
x
```

```
s
-90
s
bend
r_mid
x
s
-90
s
bend
l_mid
x
s
-90
s
bend
r_tip
x
s
-150
s
bend
l_tip
x
s
-150
s
bend
r_thumb2
y
s
-145
s
bend
l_thumb2
y
s
145
s
bend
r_shoulder
z
s
-20
s
bend
l_shoulder
z
```

```
s
20
s
bend
skull
x
s
10
s
d
;;;;;;;;;;;; end frame 1
/*********************************************************/
```

Work commenced on local motor programs (lmp's)[12,13].

In terms of movement there are only two things that a muscle can accomplish. There is one which is active, that is its ability to flex or shorten its length. The second is passive, that is to relax. So human movement can be classified anatomically into six various types. They are the following: flexion, extension, abduction, adduction, rotation and circumduction. (Figure 6.)

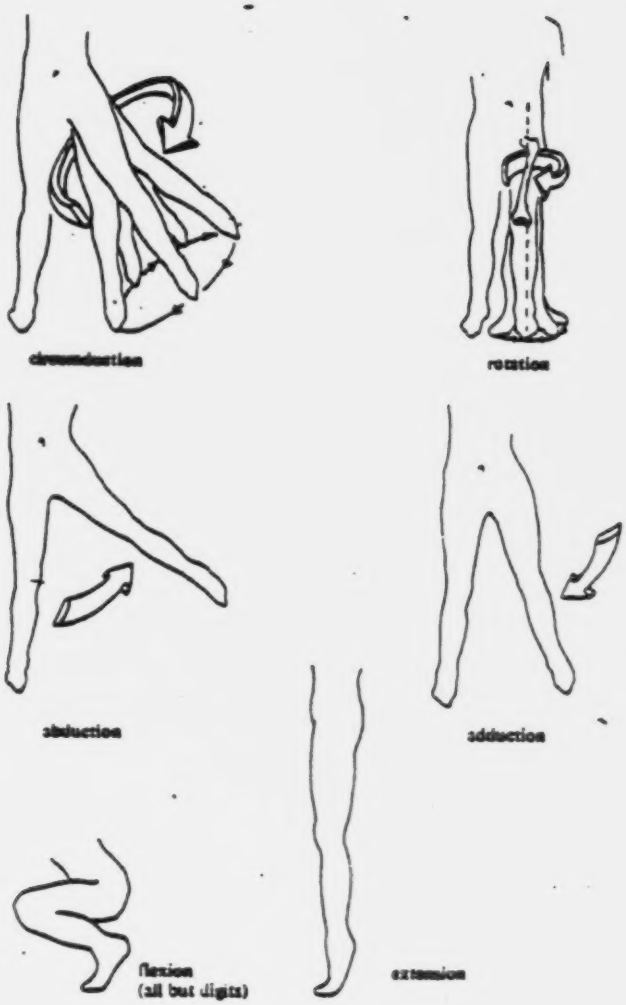


Figure 6. Movements of the Body.

Local motor programs were written to simplify a given movement. These were short programs written in the C language. They allowed the animator to specify a particular

joint action, the degree of movement, and speed. For instance a program was written to allow the user to abduct the skeleton's shoulder out to 90 degrees at a certain speed. In this way a user need not be concerned with specifying what axis to do the movement. Knowledge of the anatomical term abduction, is all that is required to request the motion. Abduction of the shoulder can mean only one thing.

Should the user ask for a wrong action with the degree of motion, the program will prompt them and inquire if they meant to do the opposite motion or the action on a corresponding joint. Depending on the user's reply, the program would correct the problem and proceed to animate the action. Initially, the command to abduct the shoulder to 90 degrees "popped" the arm out to 90 degrees. Later programs were designed to create all the various segments or frames in between the original position and the position desired. A hundred frames of movement can be written in one request. This is the direction that we are seeking. To design an intermediate language that could be used to write movement procedures. Animators could use this language to direct their characters at will.

The following is an example of code written to simplify the user input:

```
/*-------------------------------------------------------------*/
flex_arm(s,a,sp)

char s; /* which side of body*/
float a; /* what angle to bend*/
char sp;

{
     int jt,body;
     int ans=0;
     if(a > 0){
          /* if wrong direction for flexion is given */
          printf("ERROR:ANGLE GIVEN IS FOR EXTENSION");
          printf("DO YOU WISH TO FLEX THE ARM?(1=YES)(0=NO)");
          scanf("%d",&ans);
          if(ans)
               a*=(-1);
     }

     /* if left arm */
     if(s=='l') {
    /* finds current angle of joint */
          jt=find_joint("l_shoulder");
          printf("ang = %f",get_curr_ang(jt,'x'));
     }
     /* if right arm */
     else {
   /* finds current angle of joint */
          jt=find_joint("r_shoulder");
          printf("ang = %f",get_curr_ang(jt,'x'));
     }

    /* bends the joint accordingly */
     if(sp=='y'){
          body=find_joint("body");
          bend(body,jt,'x',-a,jt);
     }
     else  bend(jt,jt,'x',a,jt);
     printf("A= %f, ang = %f",a,get_curr_ang(jt,'x'));
}
/*-------------------------------------------------------------*/
```

The new user code would be as follows:

```
what action : fa (flex arm)
what angle : 45  (degrees from its current position)
```

This concept can be taken a step further by

establishing procedures for common human movements. Already implemented is a walk procedure. The a user can specify a point of origin and one of destination, and the algorithm will calculate all the complex stages of walking from point to point. (Figure 7.)

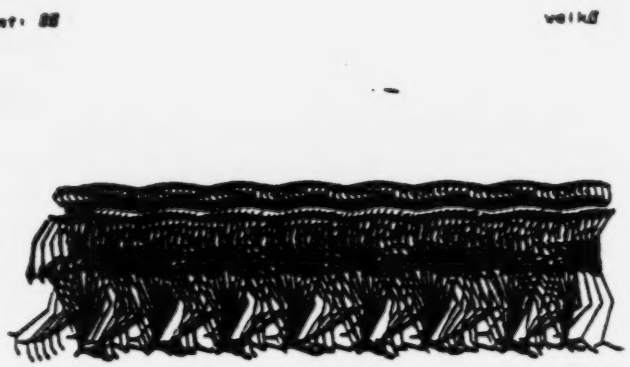


Figure 7. Test frame off Megatek showing walk sequence.

Work has also begun on implementing a reach procedure. That is given a point in space, (X,Y,Z) and the skeleton will, if close enough, reach out and grasp that point in a highly

believable fashion.

The procedures can be combined so that if the skeleton is not close enough, he will walk over and then reach the point in question. Also planned is a procedure to open things. A language parser is being developed so that given the command "Walk over to the refrigerator and get a can of beer.", the skeleton will do just that. There will be enough environmental information provided that the skeleton will know where he is at, where the refrigerator door handle is in space and direction, and which of the contents of the refrigerator is in fact a can of beer. In this way, computer generation of actors has been born.

At the same time that the movement programs were being written, work began on "fleshing out" the the vector skeleton. Animation tests were executed. This required the application of the transformation matrices that SAS output to the data. The motion was tested by displaying the data on a raster frame buffer.

In order to do animation a three-dimensional skeleton was constructed. A data generation system transferred the vectors into faceted cylinders. And after successfully displaying the tubular skeleton on the frame buffer, work began on a more precise and accurate representation of an

anatomically correct skeleton. (Figure 8.)

Figure 8. Tubular Skeleton. (Note: Paddle Hands)

Section 2. Complex Data Generation

Initial work began with the skull, the most complex collection of bones. (Figure 9.)

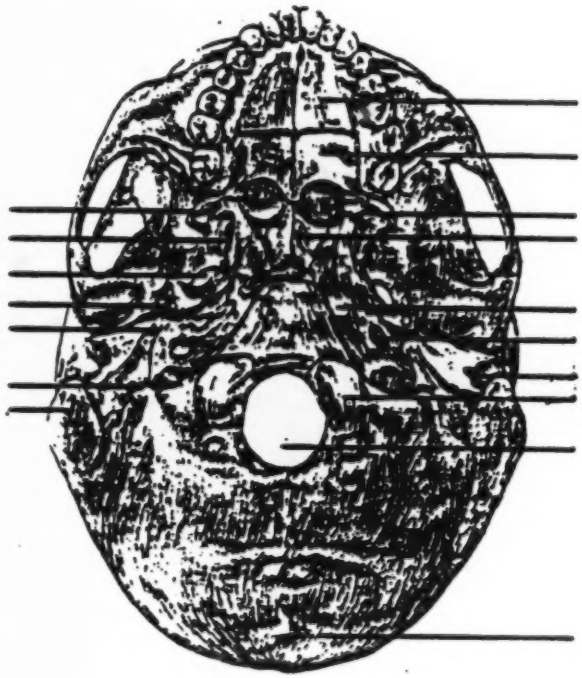


Figure 9. Inferior view of Human Skull.

Digitizing the skull presented a problem which would reoccur time and again in constructing an anacomically correct skeleton. A trade off between complexity to achieve

realism and maintaining simplicity for animation purposes exists. It is self defeating to create data for animation that is so complex that any given frame consumes up to 20 - 30 minutes of calculation time. The data of the skull had to be redesigned to achieve a sense of realism and yet be "trim" enough to calculate relatively quickly.

After several unsuccessful attempts with various methods of data generation, the process of lofting was chosen as the best to solve the unique problems that creating the data for the skull entailed[2]. The deep recesses for the eyes and the nose were special problems, as was the problem of representing the zygomatic arches. The entire skull, excluding the mandible and the teeth was constructed from 26 separate transverse levels. These levels were drawn upon an actual skull and then the points were projected onto drawings of a frontal or XY view and a lateral or YZ view of the skull. In this fashion the points could be crossed referenced to depict three-dimensional points. Since no side of a face or skull is the mirror image of the other, the freehand drawings were used to impart a sense of asymmetry.

The process involved entering the 26 different levels one by one and the program then connected the points from one level to another. In areas where the structure was

either a projection or a recess, the program allowed the user to connect specific points from one level to another. In this way the user could interactively control the way in which the points were to be connected. (Figure 10.)

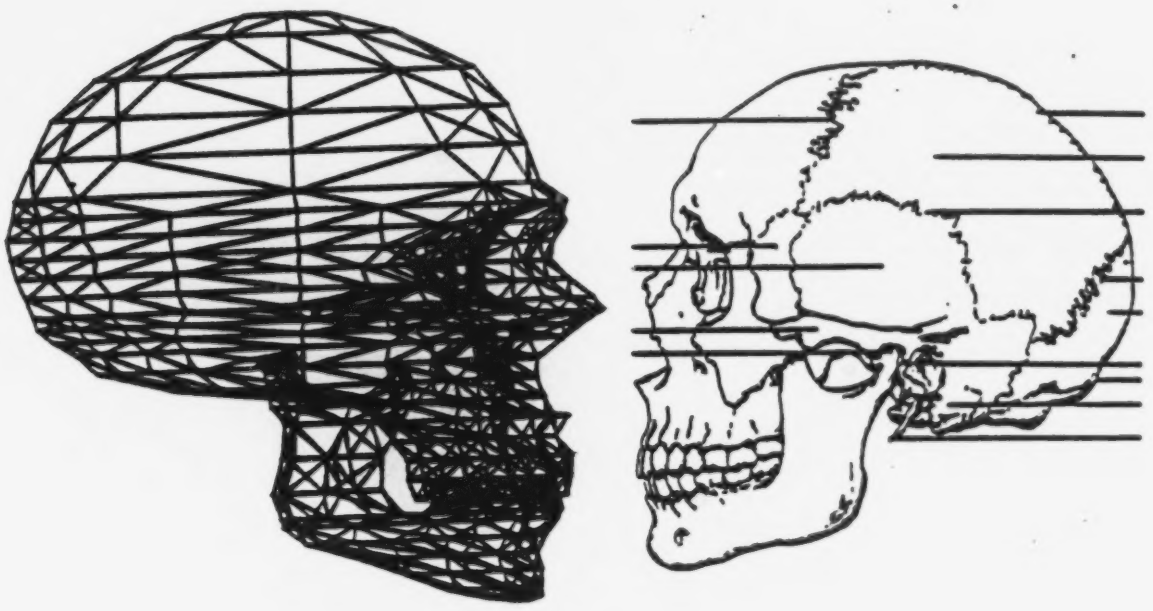


Figure 10. Left - computer generated skull. Right - illustrated skull.

The jaw presented a different problem. Due to the

strange configuration of the mandible in three space, the structure had to be divided into halves in the mid-saggital or the YZ plane. Then a side was digitized by dividing the structure in horizontal slices, interpolating the points, entering them in the computer, and connecting them in the loft program. Then by copying the side, and scaling it in X by a negative value, and running the data through a routine that reversed the order of the polygons, a mirror image of the side of the mandible was created. A complete mandible was constructed by combining the two sides of the jaw. (Figure 11.)

The teeth were constructed separately. As physically separate data from the bones of the skull, different surface attributes could be requested in the display routine. Thus a shiny pearl white quality was used to describe the teeth while a flat bone white quality was used for the bones of the skull. Unfortunately, due to the attempt to hold the amount of data to a lower limit of points, the teeth were simplified and hence came out appearing like a cheap set of dentures. However for animation that does not get close to distinguish the detail of the teeth, they are adequate. If a close up of the skull would prove necessary, a more realistic and time expensive set of teeth can be used in place of the simplified version.

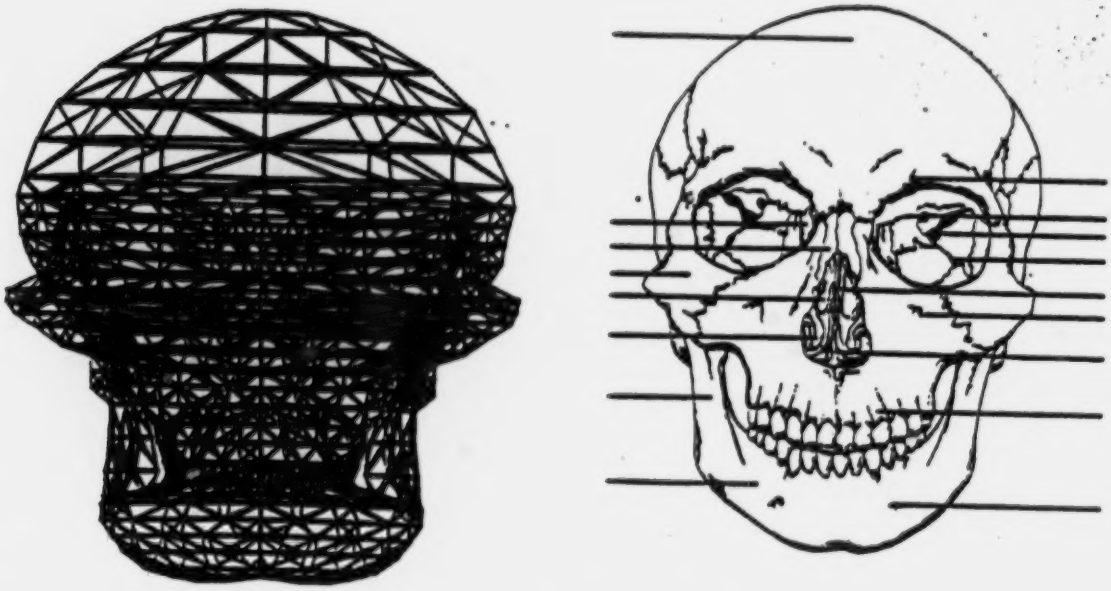


Figure 11. Left - computer generated skull. Right - illustrated skull.

Since the human form is bilaterally symmetrical, only one side of the skeleton had to be constructed. And then by using the process mentioned above,i.e. copying the object, scaling the copy in X by a negative value, and then reversing the polygonal structure, the other side of the body could be constructed. (Figure 12.)

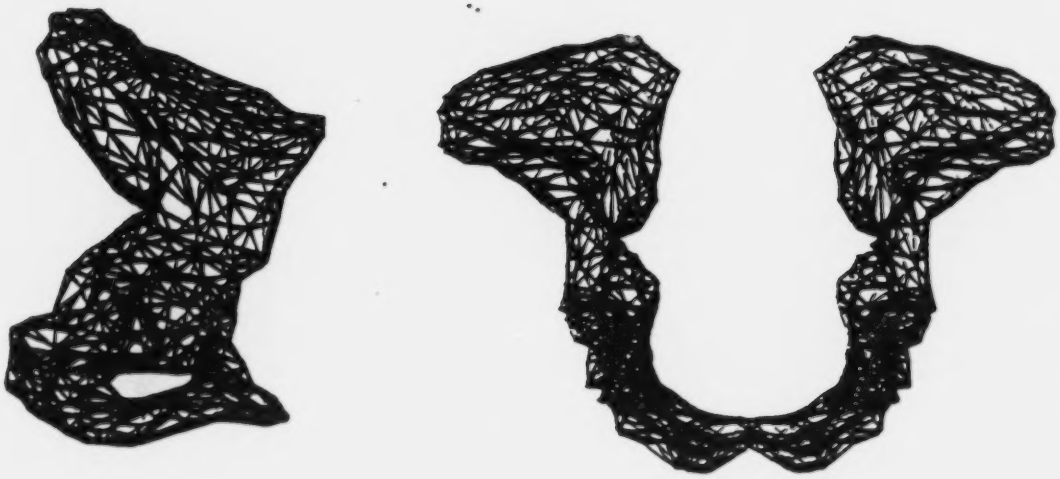


Figure 12. Left - left half of pelvis. (medial view) Right - two halves united.

The long bones were created by using four profiles (anterior, lateral, posterior, and medial) in solids of revolution. The program started with the anterior profile and interpolated the points for the next successive profiles until it reached the lateral profile. By proceeding to the posterior profile, then returning to the anterior profile a

complete 360 degree revolution was completed. (Figure 13.)

Figure 13. Top row - ulna and bones of the upper extremity. Anterior view and Lateral view of upper extremity. Bottom row - femur and bones of the lower extremity. Anterior view and Lateral view of lower extremity.

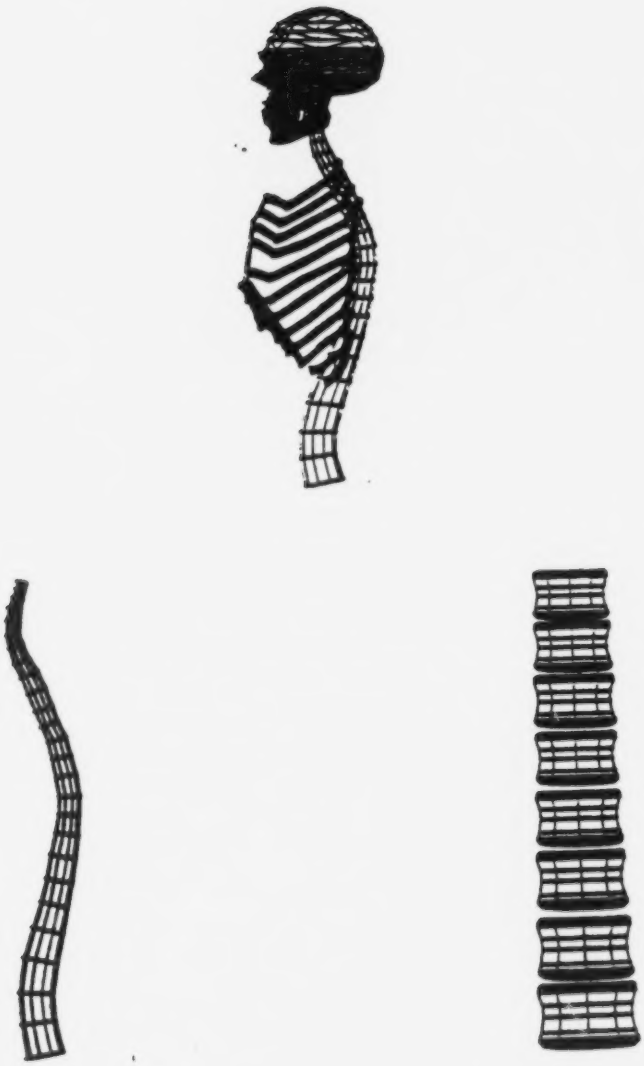


Figure 14. Axial skeleton - lateral view. Bottom row - Tubular spine and vertebrea for new spine.

The hands and feet presented an even different structural problem. The metacarpals and phalanges were made by creating a single representation of a matacarpal or a phalanx. Then the copies of the bones were scaled and translated into position. The carpal bones of the wrist and the tarsals of the ankle were created through the lofting process. (Figure 15,16.)

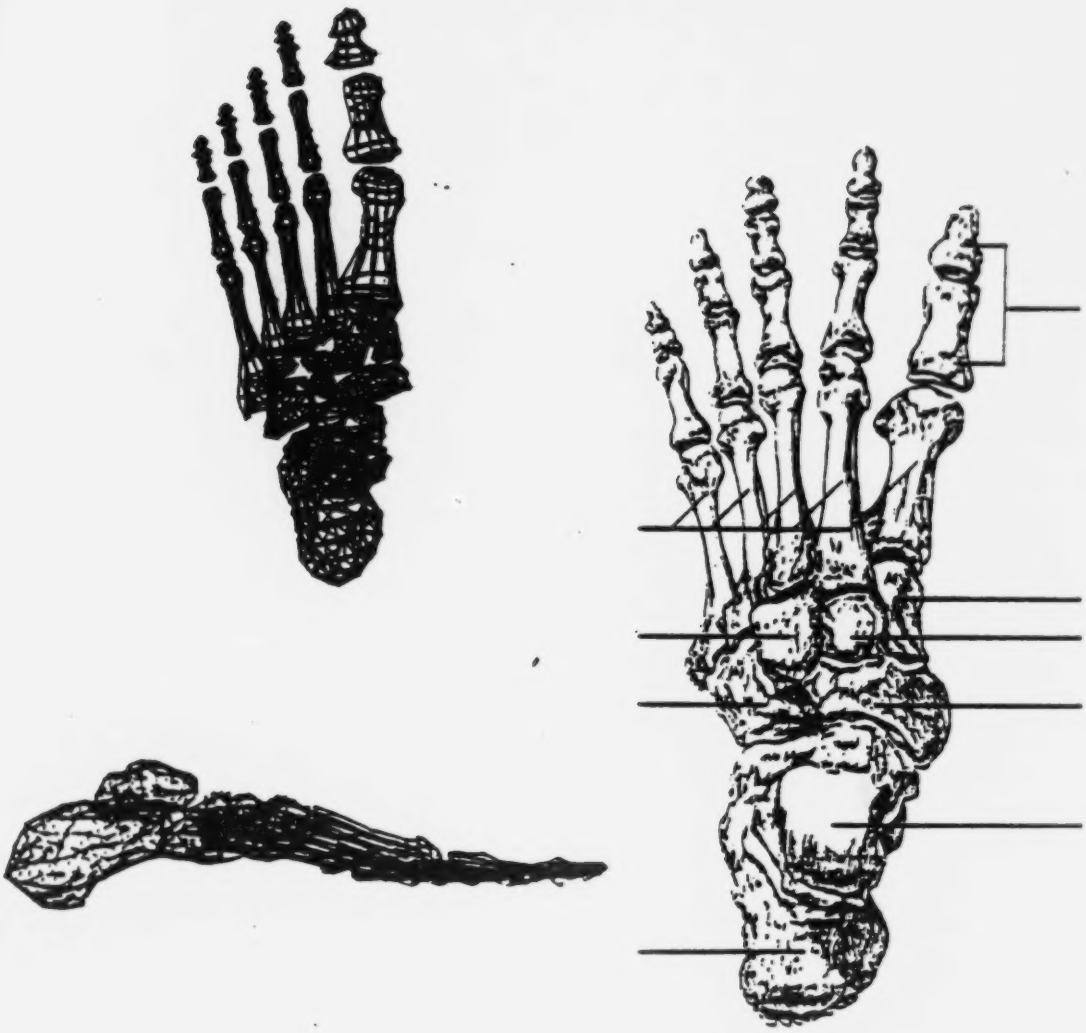


Figure 15. Left - top dorsal aspect of computer generated left foot. Far Right - illustrated foot. Left - below medial aspect of computer generated left foot.

Figure 16. Computer generated left hand.

Chapter 5: Prosthetic Data and Animation

As a spin off from previous work in skeletal animation and medical illustration, I designed animated shorts of prosthetic implantation. Discussions with surgeons indicated a general interest in the ability to depict a surgical procedure through animation.

As the term is defined, "to illustrate" means to make clear by giving or by serving as an example or instance; and to provide with visual features to expound or explain. The key word is clear in the proceeding definition. Surgeons are interested in the ability of the illustrator to abstract the essentials pertinent to a given technique or step of a surgical procedure. Extraneous information or structures obvious to the specialist are not necessary to accurately demonstrate the process and often serve, or disserve, to dissipate the desired focus. Computer animation provides an excellent way to design surgical and medical animation. The artist can work much more closely with the specialist due to the rapid turn-around time.

The first animated short designed dealt with the removal of a cataract and the correction of aphakia with an artificial anterior chamber lens. Due to the general symmetry of the eye, the data was not difficult to create. In

fact the basic four structures, the lens, the sclera, the iris, and the cornea were all made by solids of revolution. The unique configuration of the iris was created by a carefully drawn cross section of the iris.

The representation of the chipping of the cataract by the ultrasound instrument presented a special problem. This was represented by using a program written to explode polygonal structures by an algorithm that separated the individual polygons, and then executes a combination of scalings, rotations, and transformations. With a few minor modifications, the program was rewritten to simulate an implosion. The profusion instrument, the suction instrument, and the ultrasound instrument were combined into one single instrument for simplicity. Following the extraction of the cataract, the animation depicts the insertion of the anterior chamber prosthesis by translating the lens into its final position. (Figure 17.)

The second short deals with the implantation of a artificial knee joint. The animation orients the observer to the various types of rotation that the human knee can accomplish. It demonstrates the configuration of the prosthesis and the simple translation of the prosthesis into its final fixed position within the bones of the lower limb.

Figure 17. Anterior view of the eye with prosthesis in final position.

Then, and most important to the purpose, it demonstrates the ability of the prosthesis to articulate upon itself in a fashion quite similar to the actual human knee. Through transparency, the final placement of the prosthetic is shown during the ongoing rotations. (Figure 18.)

The construction of the data for the upper metal portion of the prosthesis presented the greatest difficulty. Due to its convoluted nature, the shape could not be created with solids of revolution. A process of lofting a group of serial sections was chosen as the most advantageous. Although the data was being created from a 3/4 view photograph, a rather close approximation was accomplished. (Figure 19.) Here it must be stated that a precise and accurate model, with all the manufacture's specifications can be accomplished if the proper orthographic projections and/or an actual model of the structure can be obtained.

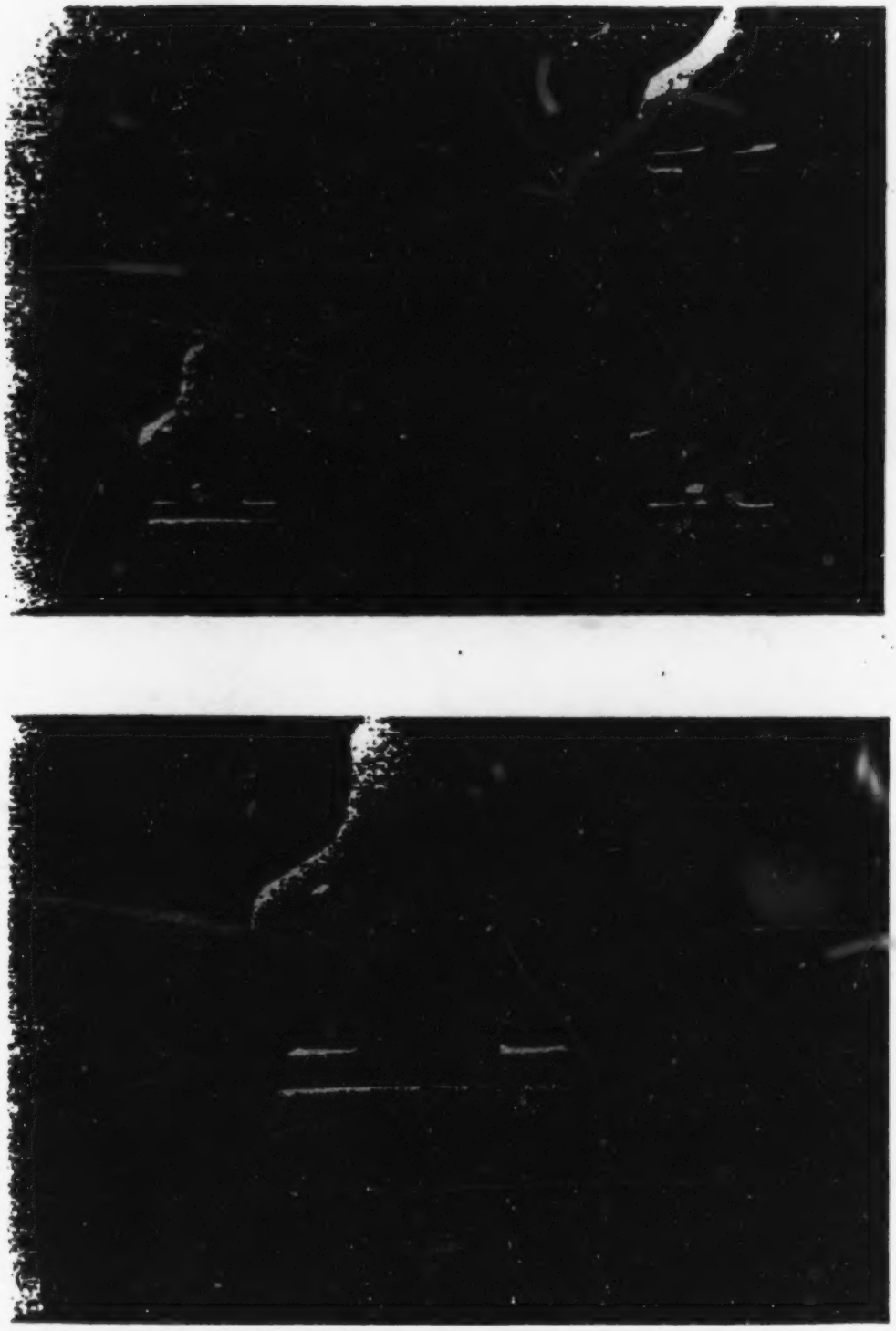


Figure 18. Top - various views of prosthesis and implant in bone. Below - closeup of prosthetic in the bones of the knee.

Chapter 6: Blood Cell and other Videodisc Learning Games

The speed at which the recent craze for video games has grown is phenomenal. It is apparent that people are willing to spend millions of dollars in quarters and stand for hours in front of a video game.

Regardless of basic drives and desires, educators need to investigate the possibilities of using computer games in education. There is a need to isolate some of the basic drives which motivate individuals to play these games and incorporate them into a learning experience. Learning can be a fun experience. If learning can be promoted through playing a game the advantage is obvious. Unfortunately, it will probably have to be done in such a subtle way that the individual does not realize that they are learning.

In an effort to address some of these issues I designed an interactive computer game called "Blood Cell." (Figure 20.) Through the game a student is introduced to an overview of the circulatory system upon a television screen. The animation segments are stored on a videodisc. The game environment consists of a videodisc player interfaced with and under the control of a microcomputer. The student interacts with the animation segments by means of the remote control buttons on the videodisc player. The program places

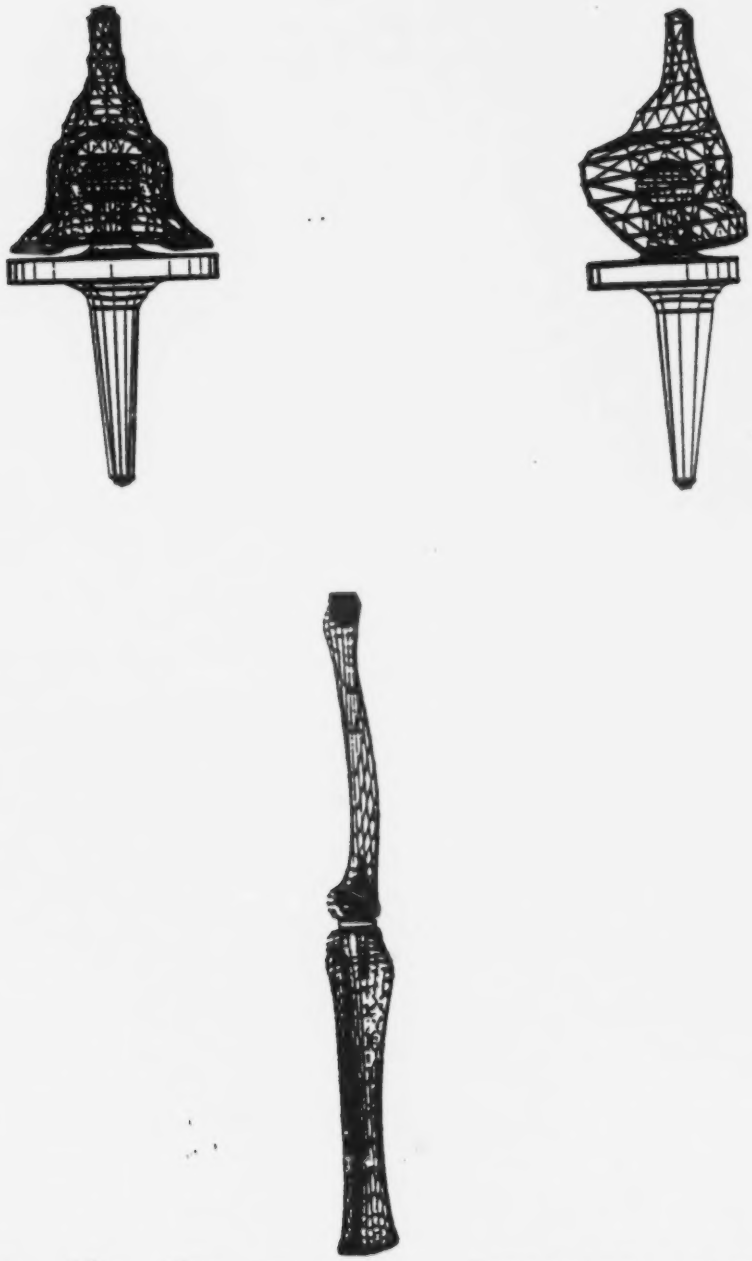


Figure 19. Top - left Posterior view of prosthesis. Top - right Medial view of prostheis. (Note: Top portion triangulated in lofting.) Below - Medial view of left lower extremity with prosthesis.

the student at a random position e.g., in a vein of the leg. A green signal flashes this position on an overall map of the circulatory system. Next the program flashes a red signal indicating a target area, perhaps an arteriole of the nose. The students' task is to navigate the vascular system making the proper directional choices and to reach the target position.

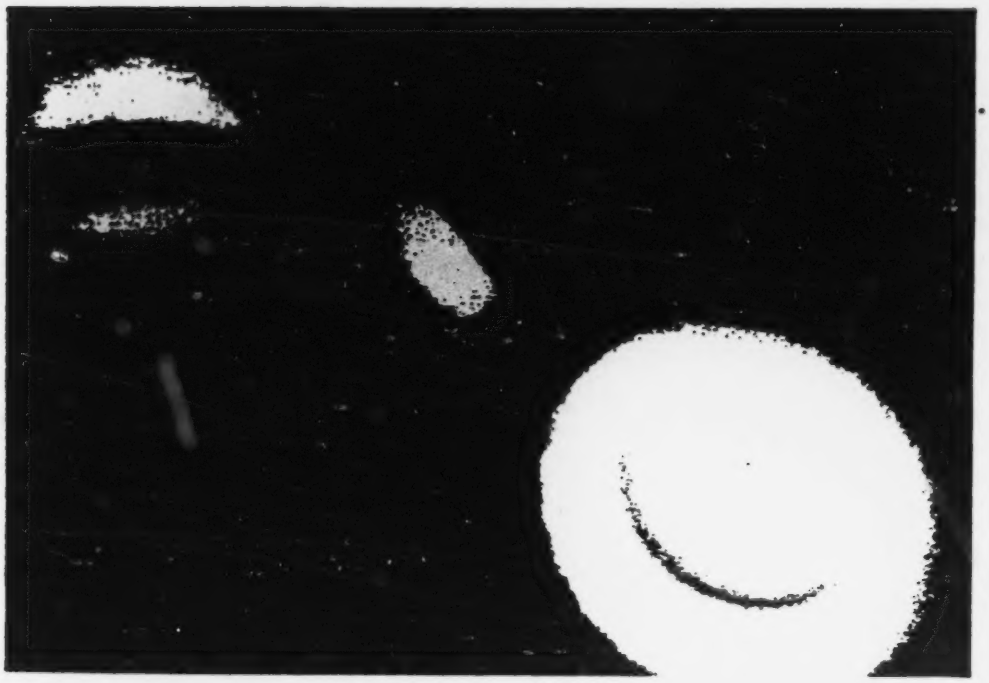


Figure 20. Frame from animation of "Blood Cell."

After the student has been given sufficient time to survey the overall system, the animation would cut to a scene of a bluish-purple RBC (Red Blood Cell) flowing through a vein. (Bluish-purple due to the unoxygenated state of venous blood.) As the RBC travels through the vein it will eventually come upon a junction, either a bifurcation, a choice of left or right, or in a rare instance, a trifurcation, a choice of left, right, or straight ahead. These are the only options.

A student can not return to their starting position because blood flow is unidirectional. Therefore the student must recall their initial position and precisely where the animation has taken them in the system.

The animation stops at various intervals for the choice given by the student. If a correct choice is made, the animation proceeds. The student sees continuing animation of a RBC down a vein that increases in diameter as they enter the larger vessels of the body. On the other hand, if an incorrect decision was made the RBC would explode (technically termed crenate) designating a mistake. If three choices were initially involved, a second choice could be input right after the first explosion. After a second incorrect choice, the view of the system would be presented

Figure 27. Computer skeleton walking across desert.

In research, the program can be used to demonstrate specific techniques that are being developed as research tools. Theoretical factors can be demonstrated for hypothesis testing purposes. This allows the researcher to graphically show what he aims at in his research prior to the actual studies.

for study.

After this study of the system view, the animation returns to a scene of the RBC coursing the correct path until once again a junction occurs. After a successful navigation to the target area the game is completed and the program tallies a final proficiency score. The microcomputer scores the mistakes by a reduction of points, and rewards correct choices with an increment of points.

Special effects of the game include the accentuation of the function of the RBC by changing the color from red to blue as the cell gives up its store of oxygen; and from blue to red as the cell regains oxygen in the alveoli of the lungs. Additional changes to color of the scene itself (representing the state of the blood) can occur. Instances of such changes in the vessels of a endocrine gland secreting hormones, or in the absorption of nutrients in the intestinal network. A particular chemical can be actively traced to target organs in more advanced levels of the game. Size difference can also be shown as when one passes from an artery through an arteriole. The RBC can be seen to gently squeeze through the walls of a transparent capillary. In an artery or the heart itself, the walls will pulsate, as they do in life with ventricular action. Different speeds of

beating can simulate various body states, i.e. sleep, non-sleep and exercise. Also valves can be placed into the system to lend authenticity.

The game can be adapted to the vascular system of any animal, to include veterinary and biological studies. In more advanced levels of the game, various developmental stages can be shown, such as the development of white blood cells, platelets, and representations of viruses and bacteria.

The educational benefits can be enhanced through the interactive capability of the videodisc. This allows for immediate correction, feedback, and self-testing on material. Such interactiveness allows each student to progress at his or her own rate. More advanced students can surpass a particular grade level of accomplishment if so motivated.

The microcomputer's ability to recall scores allows an instructor to monitor student participation and progress whenever desired. This tracking ability can remind the student of his previous scores and his most successful score to date.

The following are some of the fundamental facts of the circulatory system that can be demonstrated in this game:

1. That blood flow is unidirectional.

2. That RBC (and blood itself) change to different colors due to the process of oxygenation and oxygen debt.

3. The basic functions of RBC's and capillaries.

4. The intricate relation of the heart and the lungs and their respective roles in the circulatory system.

5. The roles of valves within the heart and veins in preventing back flow due to pressure gradients.

6. The role of blood in absorption of assimilated nutrients for body fuel.

7. Basic understanding of the configuration of the circulatory system.

8. Specialized vascular system of various organs, e.g. kidneys.

9. The function of portal systems such as those found in the digestive system and the pituitary gland.

10. Various blood cell types such as platelets which are completely destroyed in the process of slide preparation.

11. Critical pressure points for the treatment of bleeding victims.

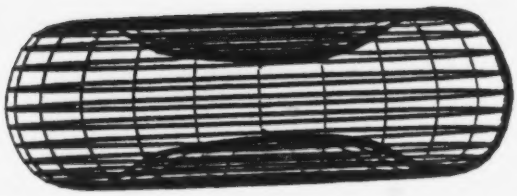
12. Alternate routes for blood in the event of an infarct or embolism.

The data that was constructed for this game was simple. It consists of a red blood cell that was created by using solids of revolution. The outline employed was a cross section of the red blood cell. Simple copies were made to show more than one. (Figure 21.)

The junction of the blood vessels was the most

difficult structure to generate. The initial structure was a simple Y-shaped bifurcation. However, due to the nature of the structure it could not be created using standard techniques, consequently the data was created by hand. It was impractical to achieve a smooth sided structure by doing the data by hand. In fact when viewing the vessel closely one could make out the polygonal sides.

There was never an attempt to construct a realistic representation of the heart. The heart is the most sophisticated and complex muscle known, not only in form but in function. (Figure 22.) In fact, a realistic representation of the heart presents so many complex data generation problems that the task has been set aside for the present. The task could be broken down into several distinct parts, however a problem arises when animation is involved. Good, clear, three-dimensional data of the heart is yet to be made available from Computer Aided Tomography (CAT scans). Several representations of the heart would have to be constructed, taken at different intervals of the cardiac cycle to achieve animation. In addition, the amount of the data must be kept to a given limit to minimize time for calculation. This creates a limit to the degree of realism and precision of the representation.



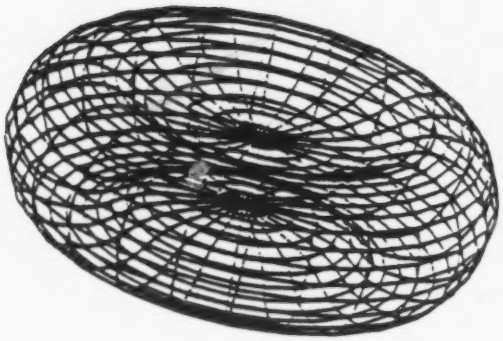


Figure 21. Top - side view showing path for revolution. Below - View of entire cell.

One approach to achieve a highly realistic view of the hearts interior would be to simply digitize a color

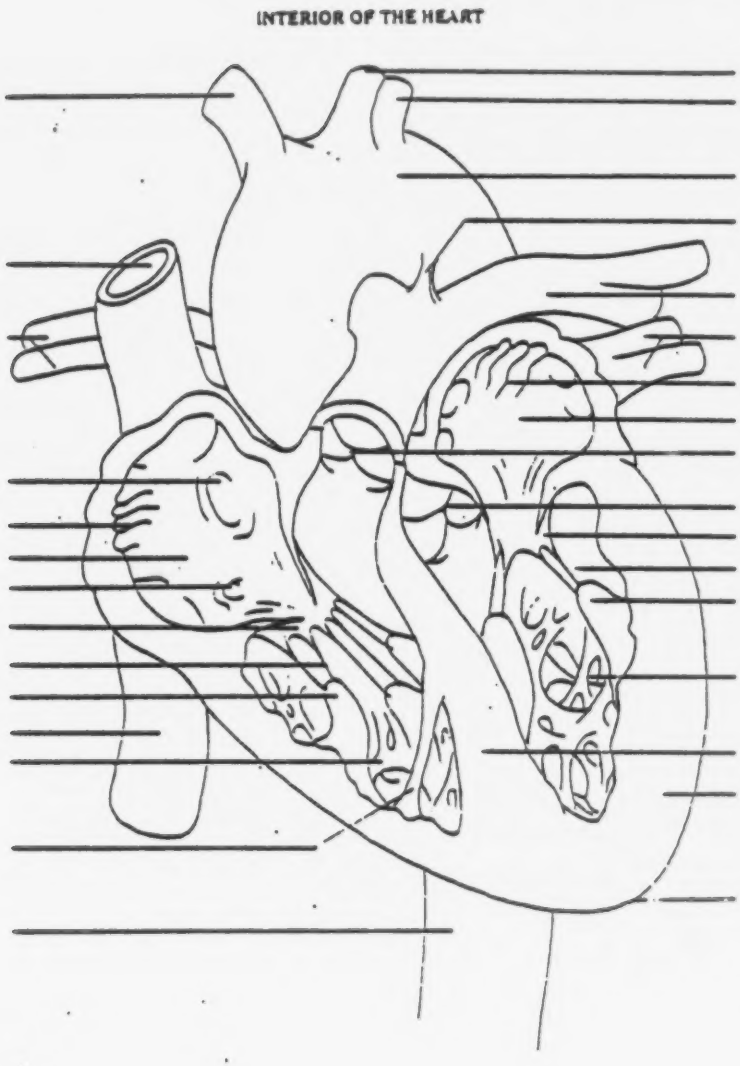


Figure 22. Illustration of the interior of the heart.

photograph or illustration of the interior surface and store

the image in the computer as a background. However, the problem of animating the surface in action still has not been addressed. The only way this would be feasible is by extremely tedious methods of representing the data as a conglomeration of parts and assigning a different shape to each part to achieve the required animated effect. This would be a Herculean task.

I worked on another interactive videodisc learning game called, "TAXI."[10]. The objectives of the game were to teach children map reading skills and to familiarize them with the address structures in a fictional city. The student assumes the role of an taxi driver. A initial position and and a final destination are given to the student. The student decides on the correct route to the destination by reading street signs and building numbers. At each intersection the student can elect to turn right, left or proceed forward. (Figure 23,24.)

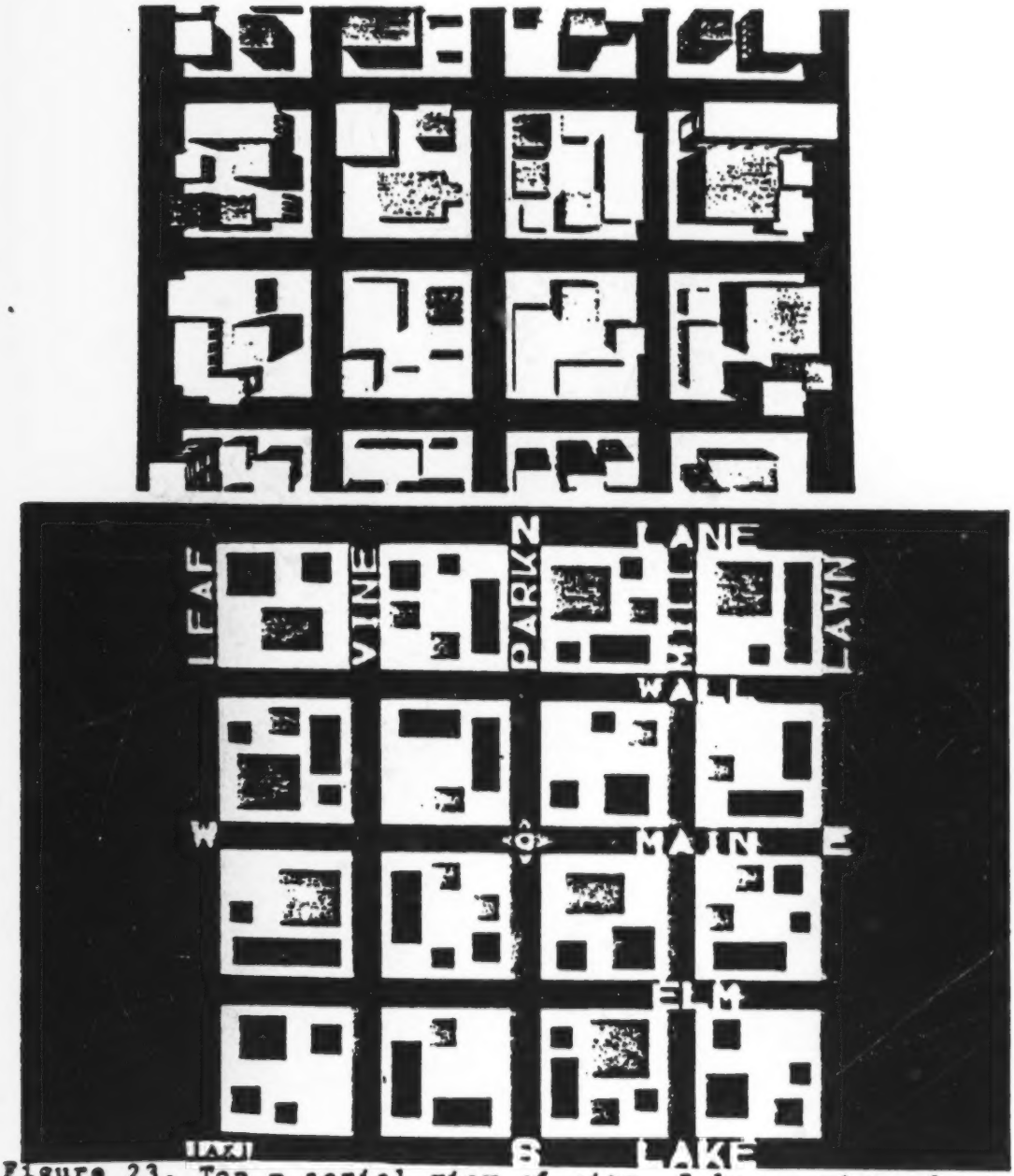


Figure 23. Top - aerial view of city. Below - view of map.

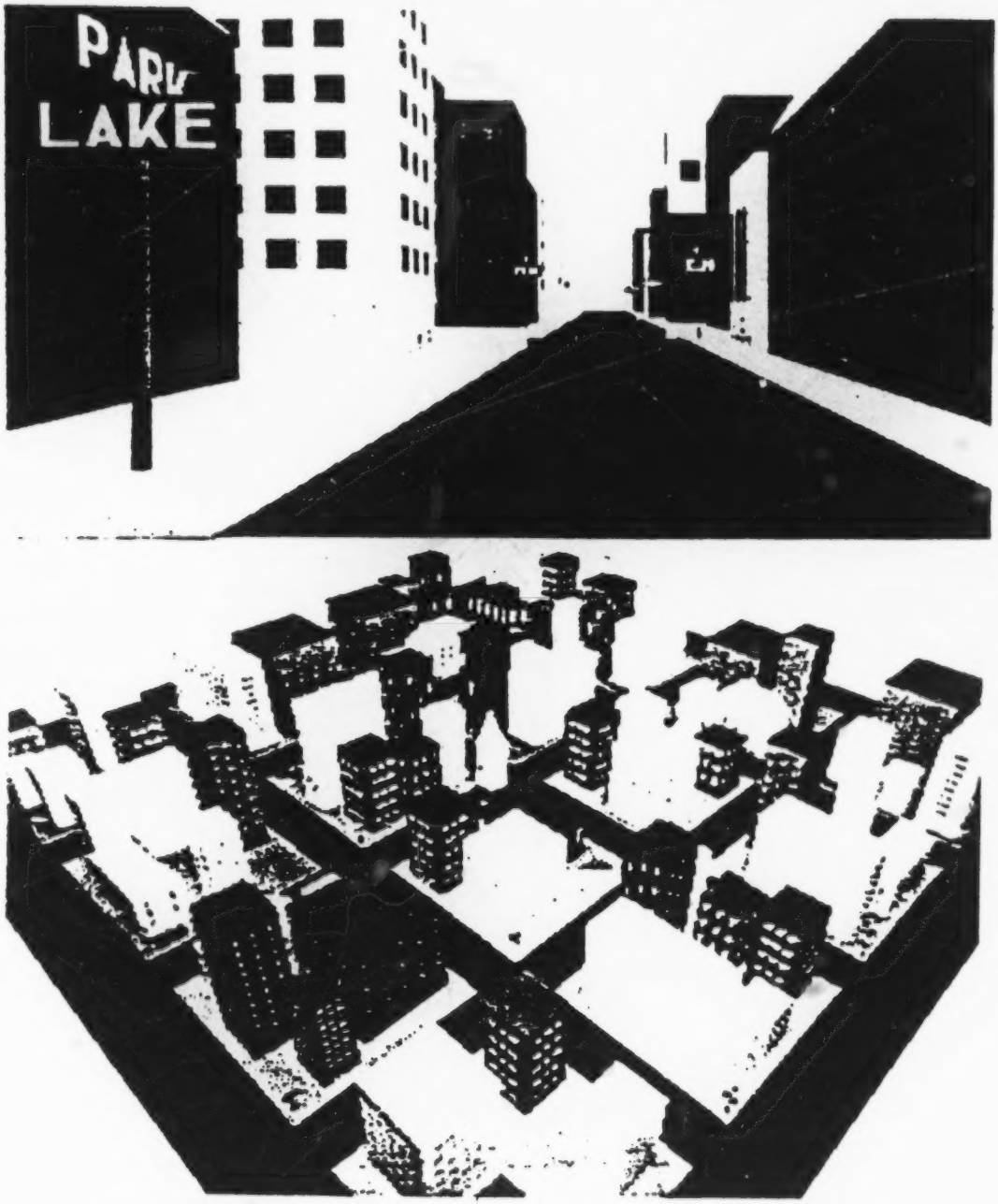


Figure 24. Frames from animation of "TAXI."

Chapter 7: The Skeleton for Simulation Research

The computer skeleton can be applied to various areas.

A language can be constructed that interprets terms found in dance for users to write a choreographic script. In this way a choreographer can design a dance and with a real-time playback. He or she can interactively work on scripts to achieve the desired effect and mood. A final script could be output and given to prospective dancers to direct their movements. There are similar programs being developed at the University of Pennsylvania that deal directly in labanotation[1]. For dancers that are not well-versed in labanotation, a more user friendly program that uses more direct and simplified terms such as arabesque or pirouette can be incorporated. (Figure 25.)

If the choreographer preferred, an actual film of the figures could be constructed showing the dance from any imaginable viewpoint. This allows the dance to be viewed not only in the more common proscenium stage view, but now as if in a theatre of the round. This can be shown to the dancers chosen for the work or perhaps used as a performance in and of itself. In addition, historical dances can be written into scripts, calculated on the computer, filmed, and then

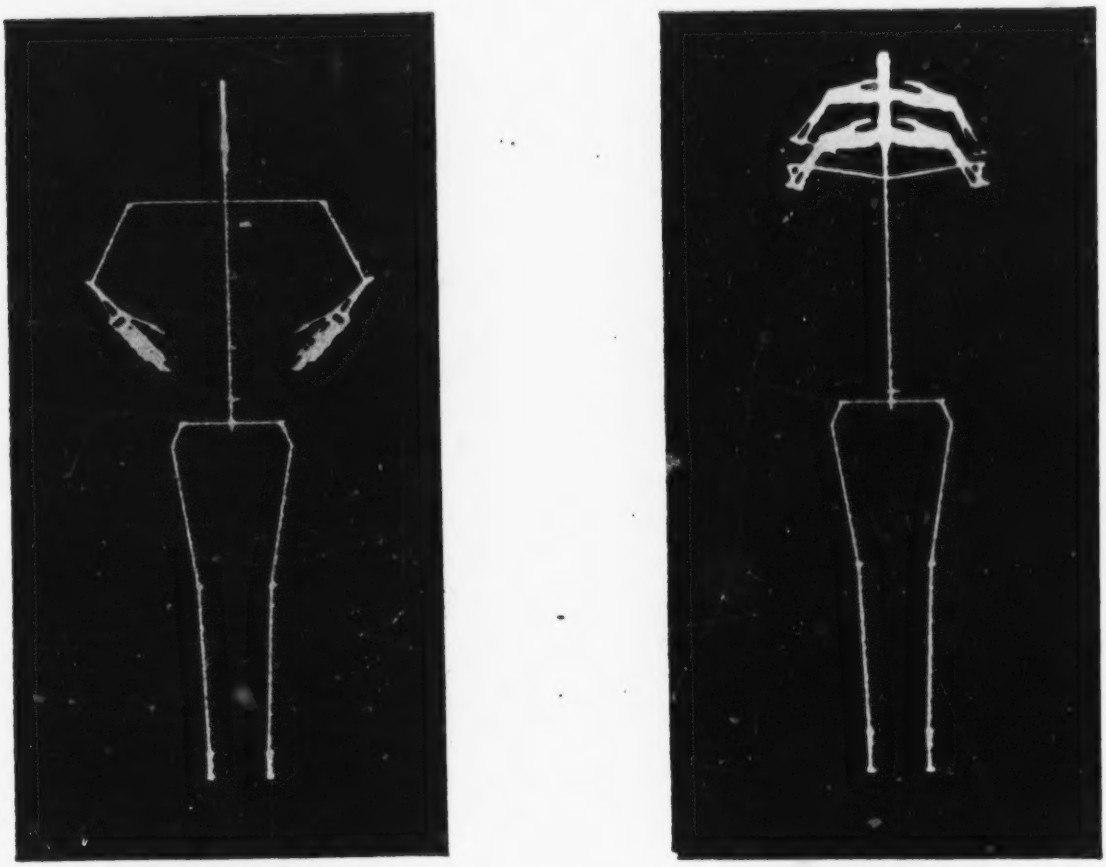


Figure 25. Frames from film for Canadian Man-Computer Communications Society '81. (pirouette sequence)

stored in an archival library. Also, non-verbal gesture studies can be made. This allows for a wide use in the art of mime or in studies of theatrical gesture. Studies of body positions and their interpretation as to meaning can be made

in an objective fashion due to the generality of the physical skeleton. (Figure 26.)

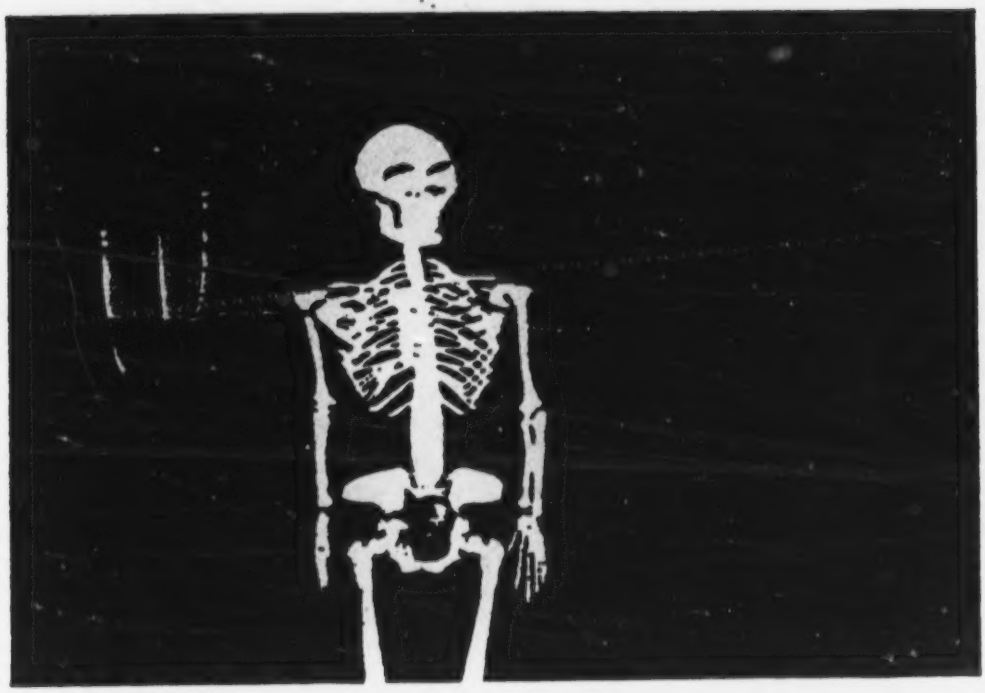


Figure 26. Frame from skeletal animation off raster display.

The program may also prove useful in the field of sports medicine. It could be used in anatomical education and in personal assessment programs. While it may not accommodate the simulation of various movements of an individual,

it may show the correct or rather more advantageous procedures and various critical aspects of the motion. It could be useful in addressing education relative to sports injuries and their rehabilitation. Training demonstrations which show how to avoid and prevent common injuries could be created.

In medical education there are several uses for such animation. Due to the kinematic approach to the design of the movement programs, various pathological conditions of motion can be studied. (Figure 27.) Educational films on the recognition of different pathologies due to disease and physical damage could be made. The ability of the animation to visually enter structures allows the viewer to gain insight into the causes and treatments of such conditions. Elaborate slow motion studies of various aspects of the motion can be isolated to show exact cause of the pathology without the use of either patient or invasive photography. Comparison to normal conditions in addition to immediate demonstration to physical or surgical correction would be made possible. A specific surgical procedure for correcting a particular pathology can be demonstrated immediately to reinforce the emphasis of both the problem and its correction.

Chapter 8: Summary

Whenever an artist is given a chance to make fantasy become reality, the imagination is stirred. I usually strive to depict thoughts and feelings that emerge on the fringe of my conscience. It is on this fringe that I base my work as an artist. With computer animation I feel I have had placed in my hands an extremely powerful tool to depict the fantasies and the realities of the imagination.

The advantage of computer animation has been exploited for some time now in the area of computer aided design and computer aided manufacturing. Only recently has the full impact of its implications to various other fields been acknowledged.

I believe that with the use of computers, the field of animation will regain the energy it once had in the heydays of Disney and Warner Brothers. The advantage of the speed in design and creation of visual information is the greatest reason for this new infusion. The revial of interest can be seen as new animation houses spring up across the country. Another reason is the cost effectiveness of computer created special effects. The use of computer actors will become more prevalent, simply because of their ability to do anything and to work for endless hours tirelessly. (Figure

28.)

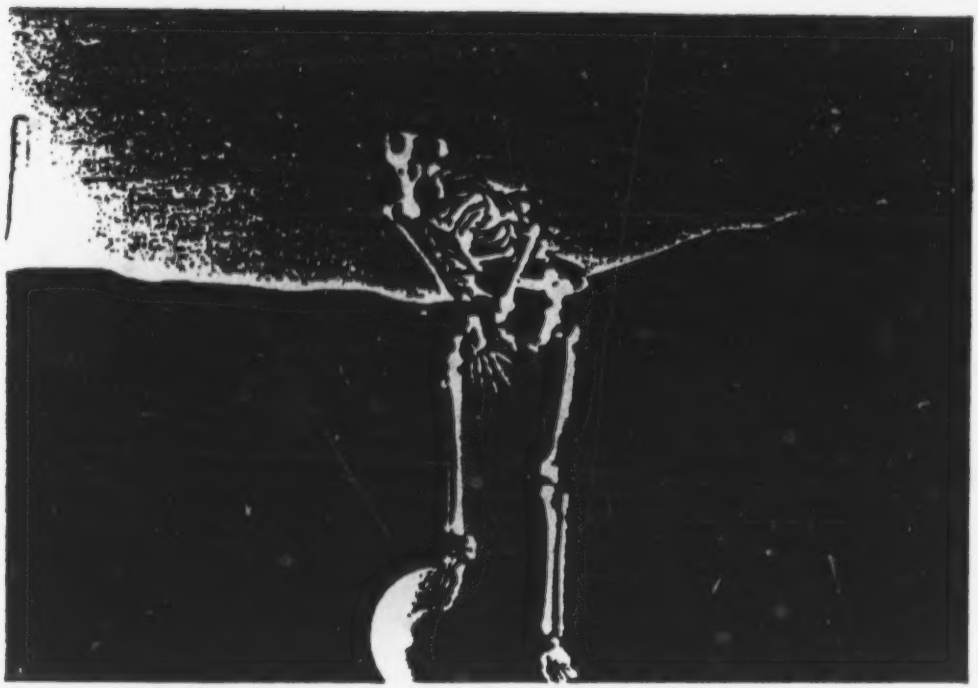


Figure 28. "Old cowboys never die.."

Glossary

1. articulated - a structure consisting of segments united at joints

2. disarticulated - the articulated structure becoming disjointed

3. anterior - a structure or surface situated towards the front side of the body (also termed ventral)

4. posterior - a structure or surface situated towards the back of the body (also termed dorsal)

5. inferior - surface that is furthest from the head of the body (also termed caudal)

6. superior - surface that is towards the head end of a body (also termed cranial)

7. medial - structure situated towards the midline of the body

8. lateral - structure situated farther from the midline of the body

9. saggital - the median or vertical plane parallel with the midline of the body

10. coronal - the frontal plane at a vertical right angle to the saggital plane

11. transverse - a horizontal plane, at right angles to both the saggital and the coronal plane that sections the body into superior/inferior

12. flex - a decrease in the angle between two articulating structures

13. extend - an increase in the angle between two articulating structures

14. abduct - a movement away from the midline of the body

15. adduct - a movement toward the midline of the body

16. rotation - a movement about the long axis of a structure

17. circumduction - a free swinging, circular motion

18. microtome - an instrument that creates extremely thin slices of tissue that has been preserved in a medium

19. cataract - a condition of clouding of the lens of the eye which obstructs the light passing to the retina

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